Food & Beverage Case Study

Client:	Multinational Confectionery Company
Location:	NSW, Australia
Treatment Type:	High Sugar Wastewater

High Sugar BioGill WWTP

Table of Contents

Glossary

STP: Sewage Treatment Plant	LAN: Local Area Network	COD: Chemical Oxygen Demand
WWTP: Wastewater Treatment Plant	IP: Internet Protocol	I/O: Inputs and Outputs
PFD: Process Flow Diagram	NOW: NSW office of water	OTR: Oxygen Transfer Rate
PLC: Programmable Logic Controller	BOD: Biological Oxygen Demand	

Project Summary

Client	Multinational Confectionery Company
Location	NSW, Australia
Volume	20 m3/day
Number of BioGill units	9. Total 2,160m² of membrane
COD pre BioGill	3220 mg/l
COD post BioGill	600 mg/l
Met client's criteria	Yes
Total investment	$300K

Since January 2015, the average discharge BOD is 284mg/L from an influent BOD of 2,330mg/L. The average daily discharge of COD is 665 mg/L, down from 2,371mg/L. The results show that the BioGill technology has reduced the liquid trade waste at the plant to comply with the regulatory requirements.

Background

A multinational food company with an established manufacturing facility in regional NSW, Australia, was facing increasing discharge fees from the local council for its trade waste liquid discharge. Food manufacturers, like many others, use water for general cleaning, rinsing, batching, blending, diluting and chemical cleaning in place, also known as CIP. Wastewater can also come from unwanted liquid batches, spills, tank overflows or discarded liquid packages.

Trigger for onsite treatment

The local council has its own environmental discharge licence with very strict nutrient limits and relies on its Sewage Treatment Plant (STP) to meet these limits. Most council STPs are designed to handle domestic wastewater. In general, the unpredictable nature of liquid trade waste can have a significant impact on the council's sewerage system and its associated costs.

The council adopted a 'source control' approach to ensure the quality of discharge remains within the capabilities of the sewage system and sewage treatment plant. This management of local trade waste discharge is managed by the NSW Office of Water (NOW). NOW is the state government body responsible for overseeing trade waste approvals. It applies a special formula with an exponential term to Biological Oxygen Demand (BOD_5) concentration to calculate the discharge fees. The client's annual discharge fees would have been in excess of $125K if no local treatment was implemented onsite. It is clear that the regulator is applying financial incentives for corporate clients to treat their wastewater onsite. Details of the calculation can be found in Appendix A.

Process Selection Criteria

Various onsite wastewater treatment options were explored, with the criteria below used to select the most suitable option:

1. Wastewater Treatment Plant (WWTP) design criteria validated using an onsite trial;
2. 2 to 3 years payback period for the initial capital cost outlay;
3. Plant is simple to operate;
4. Plant is easy to maintain;
5. Maximum one day downtime period;
6. Plant control system to be connected to the site LAN allowing for remote access and alarm notifications to be sent to the operator;
7. Plant to have flexibility to meet varying mass loads;
8. Plant to operate in cold winter weather where water drops below 12 ^{0}C;
9. Plant to allow for future upsizing to meet future demand; and
10. Low running cost.

Onsite trial

A trial unit was set up onsite comprising an IBC and a 50m^2 benchtop BioGill. The client ran the trial under different hydraulic and mass loads. Temperature effect on performance was also tested by wrapping the BioGill bioreactor with a heat blanket. The flux removal rate quoted by BioGill was confirmed by the client.

BioGill Technology

BioGill is an above ground, non submerged bioreactor. BioGill uses flat proprietary substrate sheets impregnated with a proprietary nano ceramic gel. The ceramic gel provides attached growth sites for bacteria and other microorganisms to grow as an immobilised biofilm. Single sheets are looped around a top hanger bar and arranged in series. The space inside a looped sheet is called the air side. The space between two sheets is called the liquid side. A single sheet is called a Gill. A bank of sheets together is called a BioGill. Wastewater is fed from spray nozzles located at the top of the BioGill. A typical BioGill schematic is shown below.

The gills are hydrophilic with high affinity to water, allowing water to sorb into gills creating a diffusive water flow pathway. Biomass grows on both the air side and the liquid side. Biomass growing on the air side is the aerobic biomass. Biomass growing on the liquid side is not aerobic and relies on electron acceptors other than oxygen like Nitrate (Anoxic) or organic substances (Anaerobic).

The gel matrix interspaces create wastewater capillaries allowing the air side biomass to feed on nutrients from the water side. Biofilms are glued together using Nature's super glue, a substance secreted by biomass to create the biofilm.

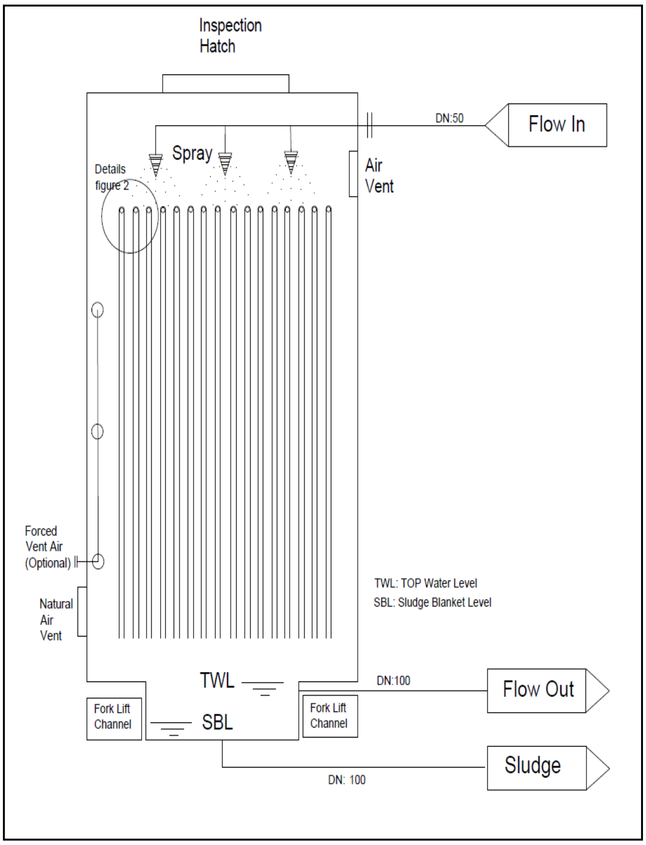

Figure 1: BioGill Schematic Diagram

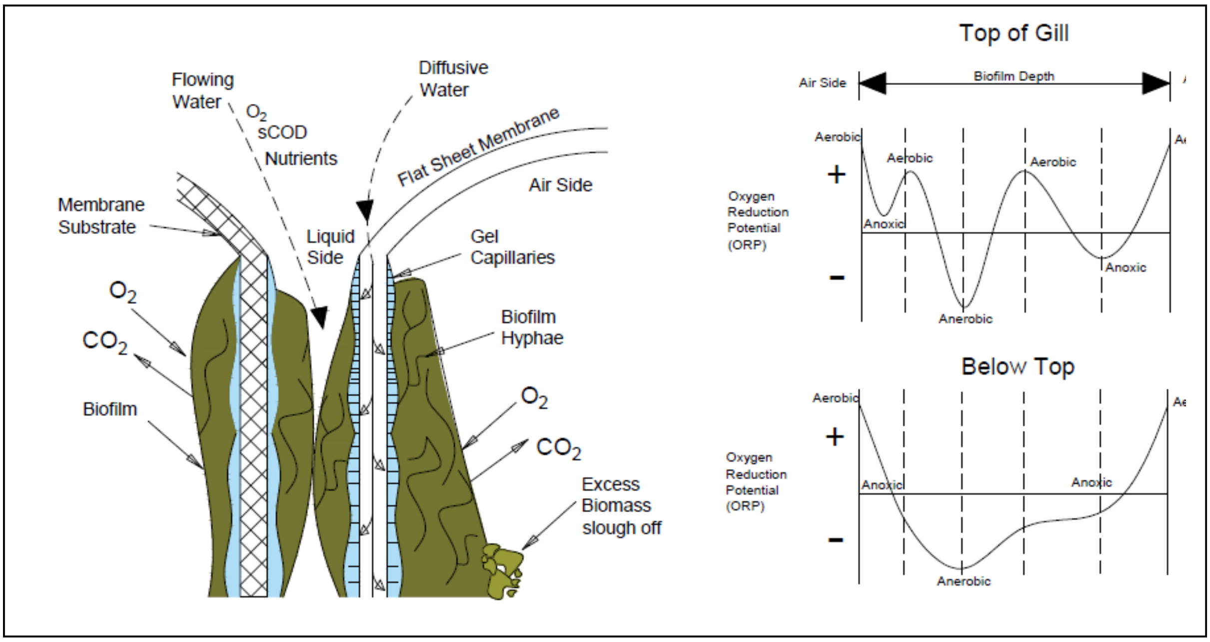

Figure 2: BioGill Depth Profile

BioGill Biological Treatment Plant

The plant is comprised of a balance tank with a mixer and transfer pump, recirculation tank with recirculation and discharge pumps, 9 BioGills in a thermally insulated shed, a pH correction system in the balance and recirculation tanks, shed ventilation fan with room temperature control, urea and phosphoric acid timer based dosing systems and a hot water solar heating system. The plant is automated with its own PLC.

In ground concrete tanks were used on this site. The balance tank holds the volume until the treatment cycle is finished. When the recirculation tank is empty, a batch is transferred from the balance tank to the recirculation tank. Recirculation pumps recirculate the batch over the gills a number of passes until the required BOD reduction is achieved. High efficiency, light weight, composite material and off-the-shelf submersible pumps were used.

The recirculation pump pressure requirement was based on overcoming general pipe losses, BioGill height (2.2m), hot water heat exchanger losses and the BioGill spray nozzles losses with total head less than 8 meters. The recirculation and discharge flows were monitored and data logged. The treatment tank level and pH were also monitored and data logged so is the room temperature and balance tank pH. Plant PFD is shown below:

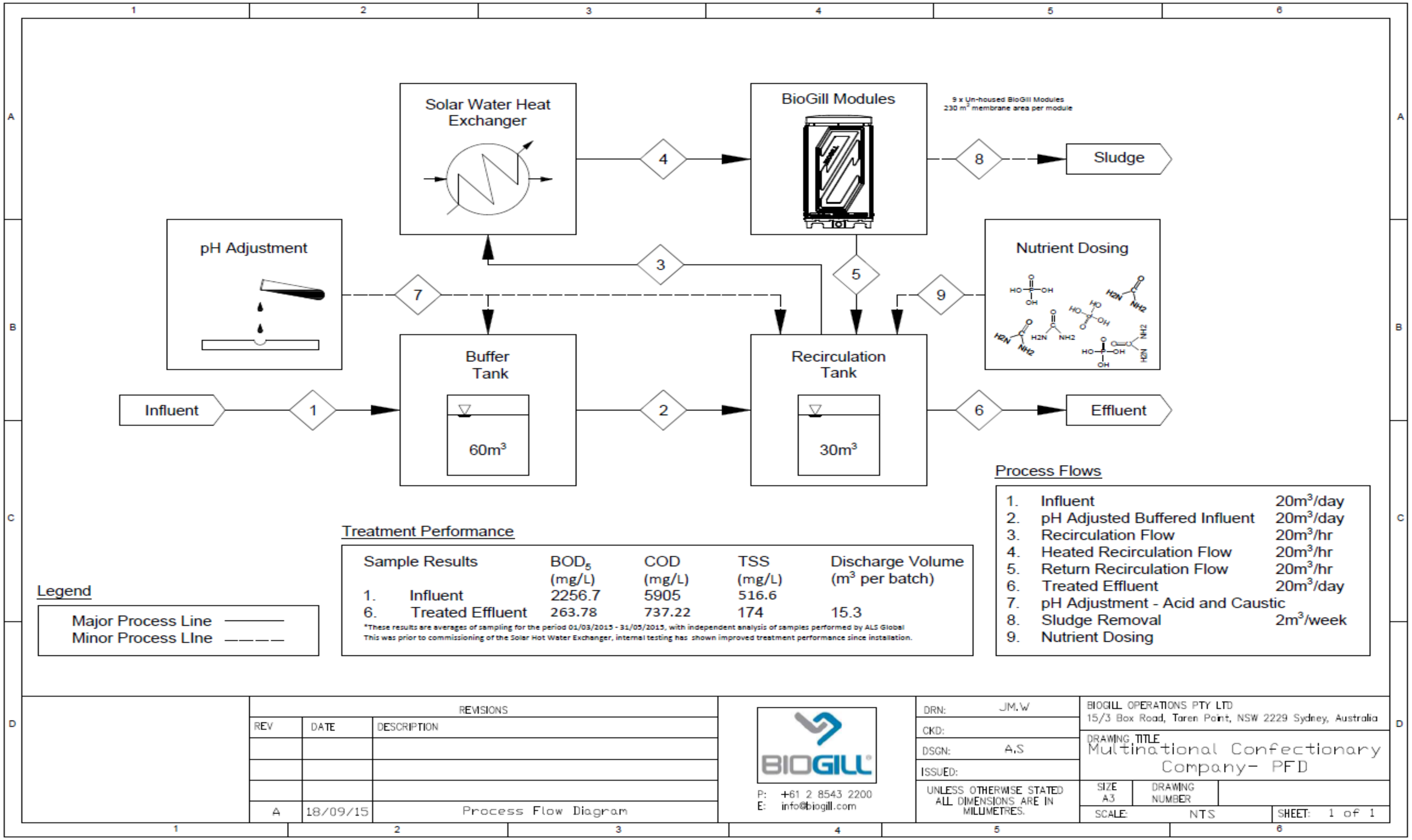

Figure 3: BioGill Process Flow Diagram (PFD)

How BioGill addressed the selection criteria

Cost effectiveness

The greatest asset of the flat sheet nano ceramic membrane is its simplicity allowing for ease of production, assembly and installation. The initial BioGill plant capital cost (including tanks, building, pumps and others) was recovered in approximately two years when considering the proposed discharge fees as running cost. Details can be found in appendix A.

Simple operation and maintenance

No custom made pressure housings are required for BioGill technology.
No specialised compartments within a concrete tank need to be designed and constructed.
No backwash or CIP cycles are required.
No scour air grid underneath membranes to reduce fouling is required.
No submerged fine aeration manifold is required in the recirculation tank.

The absence of the above process units allowed BioGill to meet the requirement of simple operation and maintenance.

Minimum down time

BioGill does not require any specialised or custom made process units. This eliminated the need for critical spare parts to be stored onsite. Since all the components were off the shelf, this allowed the operator to achieve the maximum one day downtime required. Critical components with more than one day lead time were provided in a duty/standby arrangement (e.g. pumps).

BioGill membranes have no moving parts. All pipes and fittings were off-the-shelf white PVC pressure and drain pipes locally sourced.

Remote Monitoring and alarm notification

The sequences above were programmed into a Direct06 Koyo PLC with integrated digital I/O and an I/O expansion slot. An additional analog input card was installed in the expansion slot. Analog inputs were used for pH, temperature and flow. The PLC was connected to the site LAN using its Ethernet port, which is now a standard practice for many PLCs. The site LAN administrator provided the static local IP address. This allowed the use of existing office network to provide remote dialling-in and alarm email and messaging notification. This was required by the regulator in the discharge licence.

Able to meet varying hydraulic and mass loads

The production facility runs several product lines and is affected by seasonal product demand. This resulted in significant fluctuations in influent BOD levels. At the end of the cycle, the operator take a sample from the treatment tank and tests for COD using an onsite spectrophotometer and COD test vials.

The test is relatively simple and takes up to two hours to obtain results. If the COD is not below the licence limit, the operator simply extends the recirculation pump treatment time until the required COD value is achieved. During process proofing, an automatic sampler was setup with samples taken over a period of time from the discharge line. Samples were tested for both COD and BOD. A ratio was established and agreed upon to calculate the BOD from onsite COD test results. BOD is the value used in the agreement to discharge and a compliant COD was calculated from this ratio.

Able to sustain the microbial activities during winter

BioGill units were housed in thermally insulated sandwich panels shed. This wall material was chosen for its excellent thermal resistance and light weight. Thermal insulation kept the heat generated from the breakdown of BOD inside the building and hence increased the removal rate. Temperature build up is an accumulative process with the building getting warmer over time. This was required to keep the heat in during winter. Solar heating was added later on to speed up the BOD break down and to heat the water during sub zero temperatures experienced in this particular site.

Able to meet future demand

The trial removal data was used to size the total area required for the full scale plant. 6 standard BioGill units (6x240 m^2 area) were required to achieve the existing demand. To meet future demand, 3 more BioGills were provided. The increased cost of the BioGill shed and bund to house the additional 3 BioGills was marginal compared to the significant increase in throughput.

The bund collecting the drain of the 9 BioGills is partitioned with a wall, with 6 BioGills on one side and 3 BioGills on the other side. Each partition has a separate drain. All drains are currently plumbed to the one treatment tank. In the future, the additional 3 BioGill drain can be plumbed into a separate tank creating a two stage BioGill system in series. This will allow for different microbial consortiums to colonise the 3 BioGills in stage 2, with the selection pressure being the lower BOD coming from stage 1 discharge, delivering greater BOD reduction using the existing system.

In a 2 stage system, a batch will recirculate through the first 6 BioGills and then discharge to the second treatment tank where it will then recirculate through the second polishing 3 BioGills. The partition wall was added in anticipation for tighter discharge regulation in the future and to give the option for onsite reuse of effluent water if needed. Onsite reuse will require additional tertiary treatment and disinfection units but no additional capital expenditure on the biological process unit.

Power Consumption

Power is consumed in wastewater treatment plants to do the following:

1. Pumping liquid to and from process units;
2. Powering control equipment; and
3. Supplying biological treatment with air.

Pumping costs are relatively smaller than aeration cost and are also comparable between the various WWTP options. The same also applies to electrical control equipment. BioGill provides significant power savings when it comes to supplying air because it relies on passive air diffusion directly from the atmosphere to the biofilm biomass. This is different to submerged biomass relying on Oxygen transfer from gas bubbles to liquid and then to biomass. Based on 3220 mg/L COD and 20 m^3/day, a total O_2 demand (OTR) of 1.9 kg O_2/hr is required. This is based on O_2 transfer in clean water. The following correction factors will need to be applied, in conventional submerged systems, to work out the Specific Oxygen Transfer Rate (SOTR) to cater for real life conditions. SOTR is what is used to size the blowers.

Diffuser Aeration Correction Factors (used in submerged biological systems) are:

1. Alpha (a) factor: Used to upsize the airflow to cater for loss of gas transfer efficiency from gas to liquid due to the water being dirty;
2. Beta (b) factor: Used to upsize the air flow to cater for the fact that dirty water can hold potentially less oxygen than clean water. This is characterised by the oxygen saturation concentration in dirty water;
3. Water Temperature: This affects how much oxygen water can hold. The higher the temperature, the lower the O_2 saturation concentration;

4. Site elevation. This affects the density of atmospheric air. This represents up to 10% increase in air flow due to the site being 950m above sea level. The air at this elevation is less dense and hence 10% more will be required and
5. Tank depth: This directly affects diffused aeration efficiency. Oxygen transfer from gas to liquid is not instantaneous and is time dependant. The less time a gas bubble spends in the water, the less time is available for oxygen to diffuse from gas to water. This means that the shallower the tank, the worse the efficiency. This is a significant factor in submerged aeration with reported efficiency between 5-6.25% per meter depending on how many aerators are installed or aerator density. This limitations makes submerged aeration unsuitable for shallow tanks which happens to be most of the off-the-shelf tanks available for volumes under $50m^3$.

When the above are all taken into account, BioGill power consumption is calculated to be approximately 0.7 kWh/m^3 while conventional systems utilising diffused aeration power consumption is approximately 7.1 kWh/m^3. This is 10 times the power required by BioGill. Details of the calculation can be found in Appendix B

Sludge Management

BOD is taken up by the biomass and used first for life sustaining activities. Excess BOD is used to produce more cells and grow the biofilm in size. Excess biomass slough off the flat sheet membranes once they exceed the membrane carrying capacity threshold. A theoretical biofilm design thickness of 2 mm is used to calculate the total system biomass. This is also in line of what was visually observed and measured on site. The unique spatial configuration of the BioGill biofilm being surrounded by atmospheric air on one side and high nutrient wastewater on the opposite side leads to greatly improved Oxygen transfer to deeper layers within the Biofilm. This is because nutrients and oxygen are not sharing the same area required for mass transfer. Oxygen is also supplied to the biomass from the water side as it gets dissolved in the water from the action of going through the spray nozzles.

Figure 4. Suspended biomass, vertically supported and surrounded by oxygen, growing on the membranes at this site.

BioGill systems run at low Food to Biomass ratio (F/M) which is a desirable design criteria. Low F/M means the system is supporting a higher population of microorganism for the given food source. Low F/M also means that we have older population that is using more of the food for maintenance energy and less for sludge generation.

The term that quantifies the above is called the endogenous decay coefficient which accounts for loss of biomass due to the oxidation of internal storage products, cell death and predation by higher microorganism. A sludge yield of 0.17 g VSS/gBOD was observed in this plant. Conventional systems running low sludge ages have sludge yield between 0.4-0.8 gVSS/gBOD (M&E, 5th Ed). Sludge is currently collected in IBC containers and sent off site.

The collection bund underneath the BioGill was built with a sloping floor to allow for sloughed off sludge falling from the BioGills to collect on the lower end. The higher end of the floor is where the drain pipes are installed. Once a week, the system is drained and the sludge is hosed off onto a collection pit. Currently the system generates approximately 6.3 kg/day of sludge. Using a Biofilm thickness of 2 mm and the total area of the 9 BioGills, this equates to 34 days sludge age.

Details of the above calculation can be found in Appendix C.

Comparison to other technologies

Design Criteria	BioGill	Complete Mix	Extended Aeration	Oxidation Ditch	SBR	Units
Food to Biomass ratio (F/M)	0.17	0.2-0.6	0.04-0.1	0.04-0.1	0.04-0.1	g/g.d
Equivalent MLSS	10800 (1)	1500-4000	2000-4000	3000-5000	2000-5000	mg/l MLSS
HRT	23.00	3-6	20-30	15-30	15-40	hrs
Organic Loading	1.93	0.3-1.6	0.1-0.3	0.1-0.3	0.1-0.3	kg/m^3.day
SRT	34 (2)	3-15	20-40	15-30	15-30	days

1. This was calculated by dividing the total biomass supported on the Gills by the batch volume
2. This was calculated by dividing the total biomass supported on the Gills by the daily sludge generated

Table 1: BioGill in comparison to submerged biological treatment technologies

Design Criteria	BioGill	Trickling Filter (3)	Units
Organic Loading	2.3(1)	0.08-0.4	kg/m^3.day
Removal Flux	18	NA	g BOD/m^2.day
Hydraulic Loading	2.22(2)	1.2-3.5	m^3/m^2.day

1. Organic loading refers to the physical volume of the BioGill modules
2. Hydraulic loading refers to the overall BioGill modules footprint
3. Source: L. Metcalf and H. Eddy, Wastewater Engineering Treatment Disposal Reuse, 3rd edition, (New York, NY: McGraw-Hill Book Co., Inc., 1991), p 615. BOD removal efficiency 80-90%

Table 2: BioGill in comparison to trickling filter

Treatment Results

A sample of influent/effluent COD and % COD removal is presented below:

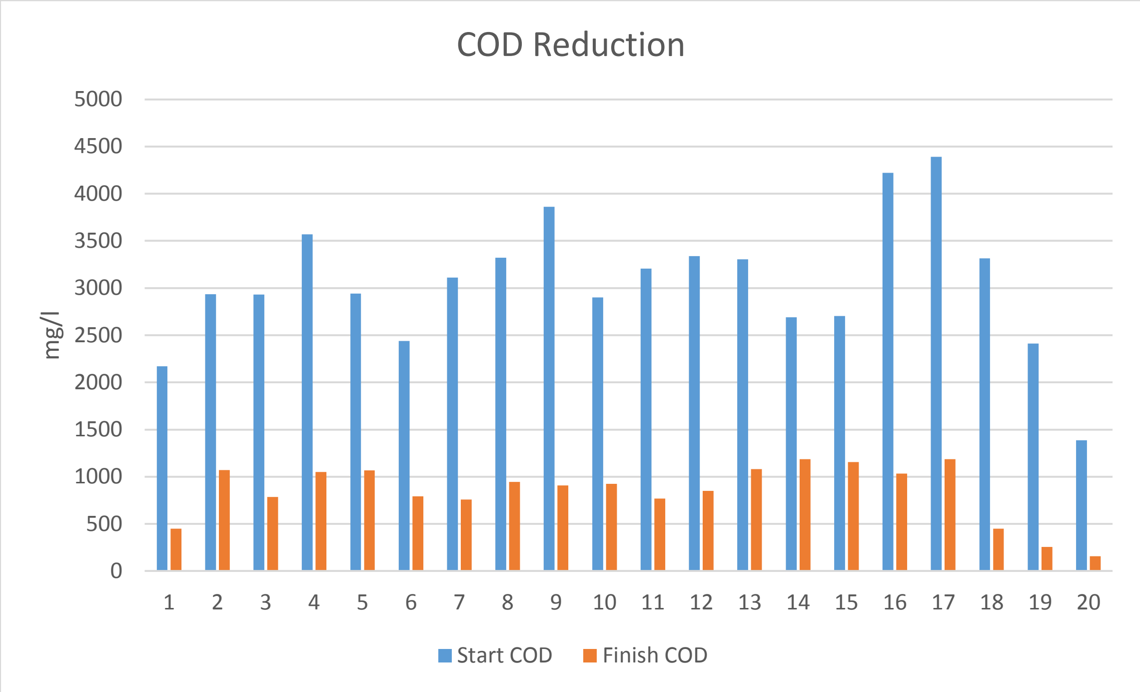

Figure 5: Comparison between influent and effluent COD

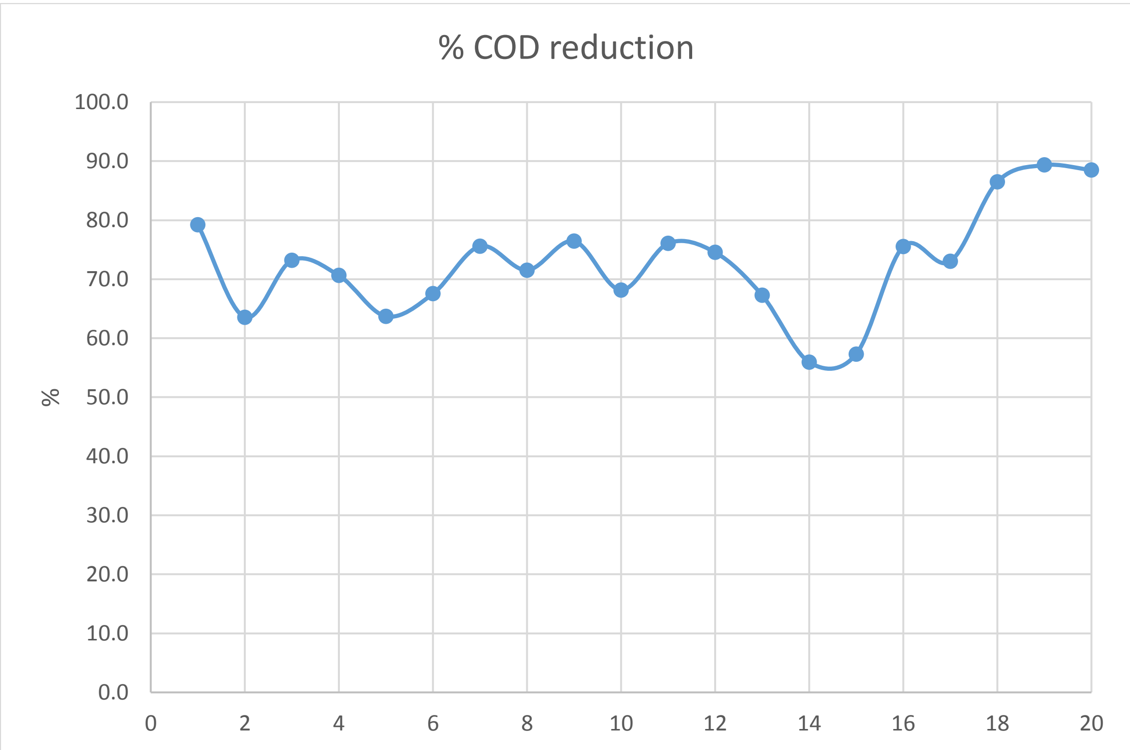

Figure 6: % COD Reduction in 20 hours

Key Learnings

BioGill WWTP pay-back was less than a year. The simplicity of the plant resulted in easier maintenance and operation. The simplicity of the control sequences meant less time was spent on PLC software debugging. The flexibility of the batch process by running longer cycles meant the operator was able to treat peak influent loads. The increased water temperature not only allowed the plant to meet the required BOD reduction in winter but also increased the plant influent load in summer. Future demands can be easily met by adding more BioGill modular units. The arrangement of the exiting plant to run in series gives the option of further reduction if required.

BioGill technology is the optimum solution for high load BOD polishing with minimum power requirement. BioGill can also be used as a pre-treatment stage for MBR, MBBR or conventional treatment to reduce size, cost and power consumption.

Further information about BioGill can be found on our website: www.biogill.com.

Appendix A: Non-compliant discharge fees calculation

NOW uses the following formula to calculate non-compliant the discharge fees for industrial customers (>20 m3/day):

$$Discharge\ Fees = \frac{(BOD - 300mg/l) \times Q \times Ue}{1000}$$

Where

$$Ue = 2C \times \frac{Actual\ BOD - 300mg/l}{300mg/l} + 4C \times \frac{Actual\ BOD - 600mg/l}{600mg/l}$$

BOD = BOD Concentration in (mg/L).
Q = Volume (kL) of liquid trade waste discharged for the period of non-compliance.
Ue = Excess mass charging rate ($/kg) for discharge of pollutant to sewerage system

Liquid Trade Waste Excess Mass charge		
S = Concentration (mg/L) of substance in sample.	2147	mg/l
D = Concentration (mg/L) of substance deemed to be present in domestic sewage.	300	mg/l
Q = Volume (kL) of liquid trade waste discharged to the sewerage system.	20	m3/day
U = Charging rate ($/kg) for discharge of substance to the sewerage system.	0.623	($/kg)
U at BOD (Compliance Charges)	4.35	($/kg)
U at BOD (Non-compliance excess mass charge)	13.04	
Flow	20	m3
Liquid Trade Waste Excess Mass charge (Compliance Charges)	$161	($/day)
Liquid Trade Waste Excess Mass charge (Compliance Charges)	$41,761	($/year)
Liquid Trade Waste Excess Mass charge (Non-compliance Charges)	$482	($/day)
Liquid Trade Waste Excess Mass charge (Non-compliance Charges)	$125,282	($/year)

Appendix B: Electrical Power consumption comparison calculations

Air Blower Power requirement

The OTR of 1.9 kg O2/l results in an air flow rate of 291 kg/hr. Power required to pump this amount of air can be calculated from the following formula:

$$Power = \frac{wRTi}{28.97ne}\left[\left(\frac{p2}{p1}\right)^{n} - 1\right]$$ Source: (Eq'n 5-77a, M&E, 5th Ed)

Where

Power is in kw
W= weight of air flow rate in kg/s
R= Ideal Gas Constant for air 8.314 J/mole.K
Ti= Absolute Inlet Temperature
P1= Absolute Inlet Pressure in atm
P2 = Absolute Outlet Pressure in atm
N= specific heat ratio. For single stage centrifugal blowers = 0.283
e = overall efficiency for blower and electrical motor

Recirculation Pump Power Requirement

The following formula is used to calculate water pumping power requirement:

$P_{h(kW)} = q\ \rho\ g\ h / (3.6x10^6)$ *Source: http://www.engineeringtoolbox.com/pumps-power-d_505.html*
Where
$P_{h(kW)}$ = *hydraulic power (kW)*

q = flow capacity (m^3/h)
ρ = density of fluid (kg/m^3)
g = gravity (9.81 m/s^2)
h = differential head (m)

Alternative technology: Fine bubble aeration flowrate design calculation – (M&E 4th,2003)			Cell Number
OTR	1.9	kg/hr, based on the COD in minus the COD of the Biomass 20*(3220-600)-1.42*5kg Biomass/day	B71
Alpha	0.5	Literature Reported Value	B72
Beta	0.95	Literature Reported Value	B73
Fouling Factor	0.9	Estimated	B74
Site elevation	950	m	B75
Air Temperature	12.0	Deg C	B76
Atmospheric pressure ratio to see level	0.9	Formula: =EXP(-(9.81*28.97*(B75)/(8314*(273.15+B76))))	B77
O2 concentration at 20 deg C	9.1	mg/l	B78
Temperature	12.0	Deg C	B79
O2 concentration at T deg C	10.73	mg/l, Formula=14.652-0.41022*(B79)+0.00791*(B79)^2-0.000077774*(B79)^3	B80
Tank Depth	3.00	m	B81
Diffuser Height	0.50	m	B82
standard Pressure at sea level	10.3	m	B83
Oxygen Conc- accounting for gas depth	9.97	mg/l, Formula: =B78*(1+0.4*((B81-B82)/B83))	B84
SOTR	6.3	kg/hr, formula: =(B71/(B72*B74))*(B84/((B73*(B80/B78)*B77*B84)-2))*(1.024^(20-B79))	B85
efficiency	0.15	5% per meter =0.05*B81	B86
density of air	1.1	kg/m3, Formula: =(B77*101300)/(287.05*(B76+273.15))	B87
O2 in Air	0.2318	w/w	B88
Air Flow Rate	2.7	m3/min. Formula: =B85/(60*B86*B88*B87)	B89
Air Flow Rate	165.0	Nm3/hr =B89*60	B90
Air Flow Rate	182.2	kg/hr. Formula=B90*B87	B91
Air Flow Rate	0.05	kg/sec =B91/3600	B92

Alternative Technology: Blower Power Requirement-M&E, eq'n 5-77, 5th ed		
Air flow rate (w)	0.05	kg/s
Ideal Gas Constant	8.314	J/mole.K
Absolute Inlet Temperature (T)	296	K
Specific Heat Ratio (n)	0.283	Single Stage Centrifugal Blower
efficiency	0.9	
Absolute outlet pressure (p2)	3	atm
Absolute Inlet Pressure (p1)	1	atm
Power to Motor	6.2	kW
Power consumption	7.1	kWh/m^3
BioGill recirculation Pump Power requirement		
No of passes	20	passes/batch
flow capacity (q)	17.4	m^3/h
density of fluid (ρ)	1000	kg/m^3
gravity (g)	9.81	m/s2
differential head (h)	8	meter
$P_{h(kW)}$ = *hydraulic power (kW)*	0.4	kW
Pump efficiency	0.8	
Motor Efficiency	0.8	
Power to Motor	0.6	kW
Power consumption	0.7	KWh/m^3
actual Pump provided	2.2	kW
Ratio of Diffused aeration to BioGill power consumption	10	times

Appendix C: Sludge Production Calculation

Biomass Production - Calculated from volume of sludge produced on site		
Daily Sludge Volume	0.30	m^3, based on 1.5 IBC every 5 days
Sludge Concentration	9000	g/m^3
TSS in effluent	180	g/m^3, average from ALS test results
Total Sludge	6.30	kg/d
Observed Yield	0.17	gVSS/gBOD
Observed Sludge Age or Retention Time (SRT)	34	days
Biomass Production -Calculated		
Flow	20.0	m3/d
BOD in	2147	mg/L
BOD out	300	mg/L
$k_{20\ DEATH\ Autotroph}$	0.1	g/g.d (Endogenous Respiration rate, Literature Reported, Table7-8, M&E, 5th Ed)
$Y_{biomass\ Yield.}$	0.60	g/g.d (Literature Reported, Table7-8, M&E, 5th Ed)
fd (Death Factor),	0.15	g/g.d, M&E, 4th Ed, Table8-10
BOD sludge without internal Biomass Recycling	22.16	kg/d = Flow x Yield x (BOD in-BOD out)
BOD sludge with internal Biomass Recycling	5.00	kg/d = Flow x Yield x (BOD in-BOD out)/(1+SRT x Yield)

End of Report